Static Structural Analysis of Parked Composite Wind Turbine Blades

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Introduction

Wind turbine blade design and development are facing serious challenges with growing size. The static structural analysis must be considered carefully in accordance with international requirements, Germanischer Lloyd and IEC61400-1 [1-2]. To perform static analysis include allowable out of plane tip deflection, surface stress and strain, aerodynamic model and blade structural model are needed. The blade element momentum (BEM) method has been employed extensively and frequently as the platform to calculate aerodynamic loads on blade. Various improvements have been published to correct limitations of original BEM such as wake rotation, 3D effects and tip loss applications [3-5]. Presented work outlined procedure of using a home-made BEM code in Matlab coupled with commercial FE package GENESIS for a static blade structural analysis. The 3.0MW wind turbine blade, from Blade System Design Study(BSDS) [6], with 49.5m rotor diameter has been chosen to validate the work, where the commercial code ANSYS(structural) and FAST-AD(aerodynamic) were utilized as a combination. The work attributes valuable knowledge in establishing static blade model in common commercial composite structural solver.

Blade FE Model

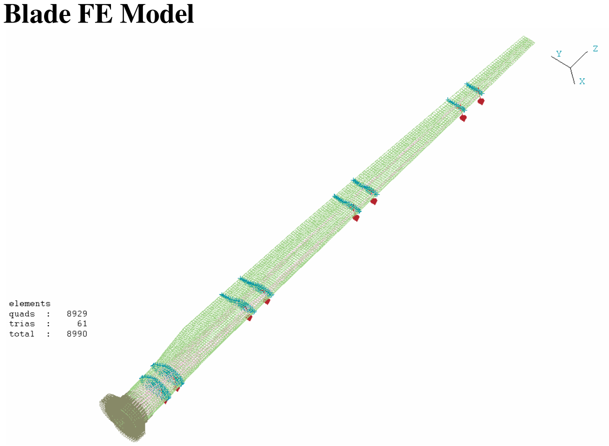

Figure 1 Blade FE model in GENSIS

Figure 1 shows the complete FE model in GENESIS for a out of plane bending at parking condition. Full blade geometry and material properties are copied from BSDS study [6]. Generally, the leading edge is built straight and the trailing edge is linearly tapered to both sides from maximum chord of 8%R at 25% station and circular blade root is designed from 5%R to 7%R before translating to complete airfoil shape at 25%R. The blade shell is formed by E-glass/epoxy. The triaxial fabric has a 25%, 25%, and 50% distribution of +45°, -45°, and 0° fibers, respectively

The spar cap is composed of alternating layers of triaxial and uniaxial fabric. In this study, the spar cap thickness is derived from a beam theory assuming spar cap is flat plate rather than aerofoil curved shape [7].

Table 1 Spar Cap Thickness Comparison

Station % R	Beam Theory mm	BSDS mm
5%	41.75	N/A
25%	37.13	39.7
50%	42.50	40.8
75%	26.36	N/A

The 50years extreme gust of 59.5m/s is tested as an example. The aerodynamic coefficients in Table 2 are calculated using modified averaged 2D-3DVC model, which is integrated in BEM code.

Table 2 Calculated aerodynamic coefficients

Station (% R)	Aerofoil	α Degree	CL_park	Cd_park
5~7	Cylinder	90	-	1.8
25	S818	79.5	0.30	1.56
50	S825	87.5	0.07	1.62
75	S826	90.0	0	1.62
100	S826	90.6	-0.03	1.62

Although a constant drag coefficient of 1.8 was used in similar study [8], it is believed minor error may exist between maximum drag coefficients used for calculation of out of plane bending load, which can be seen in Figure 2. Clearly, the flapwise bending moment is predicted closely to proposed results from BSDS but relatively large error was seen for edgewise bending load due to different aerodynamic models, which results significantly different lift coefficients. Fortunately, the edgewise deflection is not part of concern in this study.

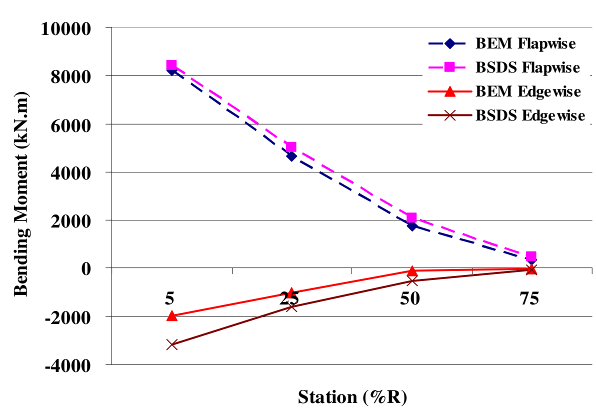

Figure 2 50 year extreme gust loading from BEM

In Figure 1, by assuming linear force distribution within each blade element and no torsion, the blade bending load can then be transformed to static point load and applied on aerodynamic center line (C/4 from leading edge) through dependent rigid body elements, which allows the DOF of each loading point is dependent of all nodes within each blade element.
Under the parking condition, the blade can be simplified as a cantilever structure. Thus the root is fully fixed in all DOF.

Results & Comparisons

The allowable out of plane tip deflection is constrained at 4.3m according to IEC standard and the BSDS predicted 4.54m with a negative 5.5% margin and the blade weights 9790kg. The presented FE analysis shows 4.24m out of plane tip deflection, in Figure 3, with a blade total mass of 9920kg. The small difference can be concluded as the spar cap thickness along span, which contribute majority of blade mass, is not mapped identically in two studies, especially at the root area. In addition, the variations in load magnitude directly influence accuracy.

Figure 3 Maximum tip out of plane deflection, mm

The critical strain is known as the design fiber directional strain, which are 1.01% and 0.45% for tension and compression, respectively. Clearly, Table 3 shows the presented model results smaller strain toward to root, which reflects the stiffer spar cap structure. Similarly as the deflection, this is due to the unidentical spar cap thickness and loading. Clearly, the BSDS is optimized to the critical design edge to minimize the mass.

Table 3 FE strain comparison over BSDS

	BSDS		Presented	
Station	Comp	Tens	Comp	Tens
Root	0.45%	0.59%	0.44%	0.37%
25%R	0.45%	0.49%	0.40%	0.47%
50%R	0.45%	0.45%	0.39%	0.36%
75%R	0.40%	0.69%	0.22%	0.28%

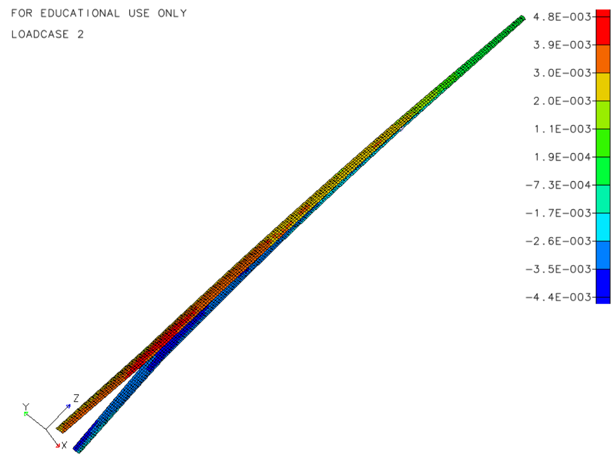

Figure 4 Spar cap composite strain in fiber direction

Conclusion

The presented static blade analysis using BEM couple FE demonstrated an easy and accurate (**sufficient data required**) approach to commercial standard. The point loading transformation from BEM bending moment output can be used to replace complicated pressure loading from CFD to significantly improve the efficiency of preliminary blade design cycle. The home-made BEM code using average 2D-3DVC model also shows abilities to predict aerodynamic behavior properly. The analysis exposes that the spar thickness is very sensitive especially from root to 50%R. A detailed optimization of composite spar cap thickness could effectively reduce the blade mass without exceeding blade design criteria. Such optimizations can be carried out in GENESIS using topology and topometry. Further study can be extended to aero-elasticity couple FE for a more realistic prediction.

References

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